A Comparison of CCD Images Taken with Different Cameras

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Abstract

The results are presented of a comparison of images taken with three different CCD cameras of the Ring Nebula, M57. An image taken with an amateur-level CCD is presented along with imagery taken with a scientific-grade chip at the 2.12-meter telescope at the San Pedro Matir observatory. Imagery of M57 from the Hubble Space Telescope (HST) archives is also presented. A comparison and contrast is made of the level and amount of information available in each of the three data sets. Angular resolution, noise characteristics and other parameters for each data set are compared in light of their impact on studying an object such as M57.

Introduction

This work is the result of an eight–week collaboration between South Carolina State University (SCSU), the City College of New York (CCNY), and Queensborough Community College (QCC). The program was funded by a grant from the National Aeronautics and Space Administration (NASA), through the Minority University-Space Interdisciplinary Network (MU-SPIN). My name is Taran Tulsee and at present I am an undergraduate physics major at Queens College, in Queens, New York. In 1999, I graduated from Queensborough Community College (QCC) with an Associate Degree in physics and mathematics. QCC has also supported my research. The objectives of my research during the summer of 2000 were:

1. To develop a better understanding of Planetary Nebulae, including their history, formation, evolution, and physical processes.

2. To gain experience in imaging celestial objects with a CCD camera.

3. To compare the level and type of information obtained with different CCD cameras and instrument configurations.

All three of these objectives were met as described below.

Modern Theory of Planetary Nebulae

The basic theory of the formation of a planetary nebulae can be briefly summarized. Starting with a star which is less than four solar masses and is a main sequence star (e.g. nuclear fusion of four hydrogen nuclei to form a helium nucleus is generating energy at the center of the star), the following will occur.

<u>Step 1</u>: Once all the hydrogen at the core is exhausted the star goes through internal changes which cause it to contract at the core and to expand its outer surface.
<u>Step 2</u>: The star may grow to 50 or 100 times its current size and turn a red color as its surface cools. It becomes a so-called "red giant".
<u>Step 3</u>: Through a high speed stellar wind and mild eruptions, the red giant throws off its outer layers which expand outward. The gas in this expanding cloud is ionized by the central star and gives off its own light. The cloud is seen from Earth in one of a variety of shapes taken on by planetary nebulae.
<u>Step 4</u>: The central star of the planetary nebula is the core of the original star since the outer layers were blown away. The central star may have a temperature of up to 150,000 K at its surface and is known as a "white dwarf". After billions of years, the white dwarf will eventually cool and

stop giving off light. The expanding gas cloud will dissipate in a few tens of thousands of years.

The ES Model of Planetary Nebulae

The Ring Nebula, also known as M57, is shown in Figure 1. It has a classic shape for planetaries, but it is far from the only shape possible. Other such objects have complicated arcs or loops of gas in emission or a gas cloud which is bipolar in shape. An example is shown in Figure 2 of NGC 6543 taken from the HST archives.

An even more comprehensive theory as to the evolution of planetary nebulae is known as the Ellipsoidal Shell, or ES, Model. It states that the central star first ejects material at a slow speed and then later at a much higher speed. The more recent ejection has caught up with some of the originally ejected material and compressed it into a shell. Additionally, there is a radial variation in density of gas as a function of position from the central star. This model, coupled with the orientation of the expanding shell relative to the observer on Earth, adequately explains most of the shapes and features observed among planetary nebulae.

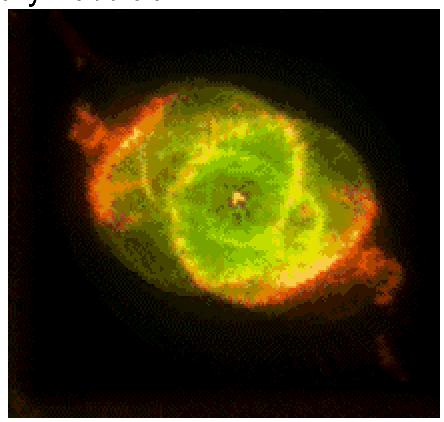


Figure 1: M57

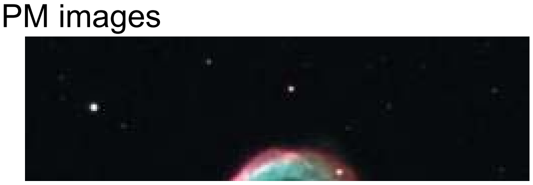
Figure 2: NGC 6543

M57 Data Sets

Table 1 summarizes the properties of the Ring Nebula, M57. Three data sets were used in this study, one from an amateur grade CCD, one from a professional grade CCD at a ground-based observatory and one from the HST archives.

The amateur grade CCD camera at SCSU was manufactured by Santa Barbara Instrument Group (SBIG) , and is the ST–7 model. The SBIG software CCDOPS was used with a PC laptop to operate the camera and store saved images while using an 8-inch, f/10, Celestron Schmidt-Cassegrain telescope. Because of cloudy and rainy weather in Orangeburg, South Carolina, we were not able to take images of M57 with our ST–7, although we did get images of the double star ε^1 and ε^2 Lyrae, shown in Figure 3, and the moon (see B. Teasdel's paper). Figure 3 was used to determine the spatial resolution of the ST-7. In place of our own images of M57 we used one from the SBIG website which had a nearly identical camera-telescope configuration. The SBIG image of M57 is shown in Figure 4.

Figure 5 is an image from our ground-based, professional grade CCD. This image is of M57 was taken at San Pedro Matir (SPM) through a filter centered on the Hα emission line at 6563 Å. It is shown inverted in color so that dark in the picture is actually bright on the sky. See the paper by K. Banks and I. Lister for more details about SPM images



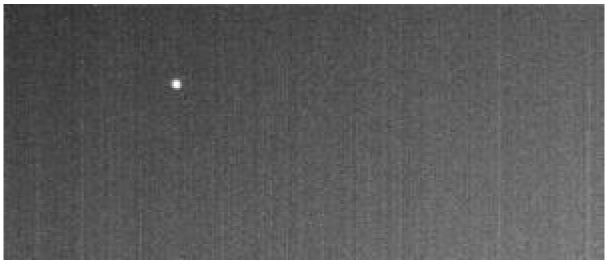


Figure 6 is taken from the HST archives. It has been rotated so that its orientation is the same as our ground-based images. It is actually a composite of several images taken through different filters and color coded to emphasize ionization differences among regions of the nebula.

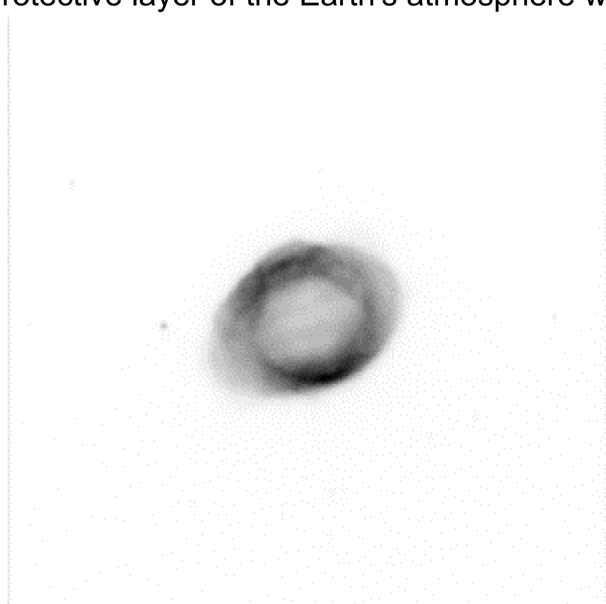
Figure 3: ε^1 - ε^2 Lyrae

Figure 4: M57

Comparison of Data Sets

Figures 5–6 have been reduced from their original raw form. Noise sources have been reduced or eliminated. For more information about CCD noise sources, see the paper by B. Teasdel which discusses cosmic rays, bias frames, dark counts and flat field corrections. The IRAF software package was used for the image processing of the SPM image in Figure 5. See the paper by K. Banks and I. Lister for more information on IRAF.

Table 2 lists the major properties of the three CCD cameras used to gather the images in Figures 4-6. The HST CCDs are clearly superior with regard to higher spatial resolution and lower dark counts. All three CCDs were cosmetically quite clean as indicated under the feature "BAD PIXEL COLUMNS" in Tables 2 and 3. The elevation of the CCD, of course, determines the number of cosmic ray hits, with HST having the most number of hits and ST-7 the least because of the protective layer of the Earth's atmosphere which blocks out most of the incoming charged particles.



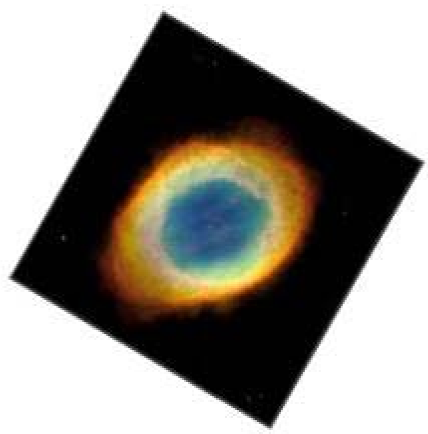


Figure 5: M57 from SPM

Figure 6: M57 from HST

Comparison of Images from the Different CCDs

Comparison of the last three images is not straightforward for a couple of reasons. The three images are taken with different filters and with CCDs which differ in sensitivity as a function of wavelength. Equipment setup differed as did exposure time. Nonetheless there are number of obvious differences.

One can easily note the superiority of the Hubble image, and this is not all due to aesthetics. The comparisons in Table 2 show that Hubble's spatial resolution is 0.1 arcsec per pixel compared to 0.7 and 0.97 for the other two CCD's. Comparison of the images shows radial striations in the nebula in HST's image. These striations are not present in the other images. The ability to image this feature results because of the greater resolution of HST, and the fact that atmospheric seeing is absent with Hubble and, therefore, does not smear out the details. For the same reasons, the faint edges of the outer part of the nebular are readily visible in Figure 6 but not Figures 4 and 5.

Another comparative effect is that of the shape and size of stars in astronomical images. Starlight coming in from infinity should form an image that looks like a point source. Only in the Hubble images are the stars approximating point sources. In the other two systems there is much variation from this ideal.

Summary

The objectives of this study were met within the eight–week period allotted. I can say that I now have a better understanding of planetary nebulae. As the images from the poster show, I have gained experience in imaging celestial objects with a CCD camera, in particular the ST–7. The comparison of different CCD's as regards level and type of information proved to be much more involved than would be at first suspected, but we were able to accomplish that daunting objective as well.

Acknowledgements

The author wishes to acknowledge funding provided for this research from NASA-MU-SPIN NCC 5-98 to City College of New York, NCC 5-116 to South Carolina State University and additional NASA funds to Medgar Evers College, New York. The author wishes to thank Dr. Donald Walter of SCSU, Dr. Donald Cotten of QCC, Dr. Shermane Austin of CCNY and Dr. Leon Johnson of Medgar Evers College. Without the help of these fine people, my participation in this project would not have been possible.

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TABLE 1

PROPERTIES OF M57

Feature	Value	Source
POSITION	RA:18h 53.6m DEC: +33° 02"	Observer's Handbook 2000
LOCATION	Constellation Lyra	Norton's 2000
LINEAR DISTANCE	1000 -- 2000 ly	Sky & Telescope July 2000
	5 x 10^3 ly	Observer's Handbook 2000
LINEAR SIZE	4 trillion miles	Sky & Telescope July 2000
ANGULAR SIZE	1.2′	Observer's Handbook 2000
MAGNITUDE	18 per sq arcsec	Observer's Handbook 2000
SHAPE	Varies depending on ion	Sky & Telescope July 2000
CENTRAL STAR MAG.	15	Observer's Handbook 2000
OTHER NAMES	NGC 6720 Ring Nebula	Observer's Handbook 2000

TABLE 2

CCD CAMERA COMPARISON

Feature	CCD #1	CCD #2	CCD #3
INSTRUMENT (MANUFACTURER)	ST–7 (SBIG)	SAN PEDRO (Unknown)	HST (LORAL)
ARRAY DIMENSIONS	1 ccd 6.89 mm x 4.59mm	1 ccd	4 ccd's
PIXEL ARRAY	765 x 510	1024 x 1024 binned 256 x 256	1600 x1600
# OF PIXELS	390150	65536	2560000

SPATIAL RESOLUTION Arcsec pixel^{-1}	0.97	0.7 per binned pixel	0.1 for 3 CCD's 0.046 for 1 CCD
DARK COUNTS s^{-1} pixel^{-1}	0.3	0.1	6×10^{-4}
MEAN BIAS pixel^{-1}	105	145	300
BAD PIXEL COLUMNS	Column 632 Rows 53 – 61	See Table 3	Increases with time
*f/*RATIO	f /10	f /7.5	f /12.9 for 3 CCD's f /28.3 for 1 CCD
LOCATION OF CCD	Earth –based sea level	Earth –based 8000′	In near –earth orbit

TABLE 3

BAD PIXEL LIST – SAN PEDRO MATIR CCD

Area	Column	Begin Row	End Row	# of Pixels
# 1	64	194	233	40
# 2	99	200	207	8
# 3	215	1	256	256
# 4	246	160	179	20
# 5	217	55	68	14